Offshore wind resource assessment with the mesoscale model mm5

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Abstract

A new challenge arising from off-shore technology wind power installations, where measurements are scarce, is the use of numerical models to simulate wind flow over the sea. This work deals with the application of the mesoscale model MM5 for offshore wind resource assessment. Focus of this investigation is the optimisation of the model configuration suitable for offshore wind resource assessment and the evaluation of the ability of different planetary boundary layer schemes to properly simulate off-shore wind profiles. Measurements from the 100 m high meteorological mast FINO 1 in the North Sea have been used for validation of the model results. It has been found that the grid resolution can be reduced significantly compared to commonly used configurations without loss in performance over the sea and that model performance deteriorates close to the cost-line depending on grid resolution. This work finally shows that the PBL parameterization plays a crucial role in the prediction of the wind profile. As an application, a simulation of wind speed for year 2004 has been performed over the German Bight and results are compared to the measurement at FINO 1. A generally good agreement has been found.

1 Introduction

Limited-area models (LAMs) are often used to calculate the wind resources for wind energy utilisation over land. For this application, a very high accuracy of the wind speed modelling is required. Additionally, there are new challenges arising from technology installation off-shore, where measurements are scarce. Thus, the wind resource often has to be assessed by means of numerical modelling. In contrary to the application over land, orographic effects are of minor importance offshore. A coarser spatial resolution is therefore, in principle, sufficient to properly describe the horizontal spatial variation of the wind speed, which significantly reduces the computational cost. On the other hand, the processes which govern the interaction between and sea surface and atmosphere are not fully described by the current models. Furthermore the lack of high quality wind measurements in the lower boundary layer over the sea has limited, so far, the number of verification studies and consequently, the application of mesoscale models for the derivation on wind conditions over offshore. Sandström [4] used a 2.5 level turbulence closure model to simulate the climatological wind condition over the Baltic Sea. The model was run for 96 conditions driven by different classes of geostrophic wind and wind direction. This work will follow a different approach, by dynamically simulating the state of the atmosphere for one year. Long term conditions can be derived by performing a post-correlation of the simulated wind conditions with a set of suitable long term data. This approach can be used as an alternative to the tools commonly used for the wind resorce assessment (as the Wind Atlas Analysis and Application Program, WAsP). A comparative study between the WASP and MM5 can be found in [3].

2 Model description

MM5 is a numerical weather prediction model developed by the Pennsylvania State University and National Center for Atmospheric Research with the ability to simulate the atmospheric conditions with resolution ranging from 100 km to 1 km. Version 3 of MM5 is a non-hydrostatic prognostic model with explicit description of pressure, momentum and temperature. The numerical solution is computed on a rectangular structured staggered grid by finite difference schemes. The vertical coordinate is terrain-following σ. Multiple domains, with increasing resolution can be nested one into each other in order to get higher resolution results in the region of interest. The nesting procedure can work both in one-way mode (the solution of the parent domain feeds the child domain) or in two way mode (the solution of the parent domain provides boundary condition for the child domain *and* the solution found in the child domain affects, on turn, the solution of the parent domain). The physical package of MM5 is made up by a set of parameterization schemes for cumulus, radiation, planetary boundary layer, microphysics, and surface processes. A Four Dimensional Data Assimilation (FDDA) scheme is implemented in the model with the capability of "nudging" the solution towards analysis or observations. A more complete description of the MM5 model can be found in [2].

3 Sensitivity of results to model configuration

Several studies focused on the sensitivity of the model results to model setup. As "model setup" we refer to the grid configuration (including horizontal and vertical resolution, the choice of the domains, the kind of interaction between nested domains) and the set of physical models used to parameterize the subgrid processes (the so called "physics" of the model). Efforts have been made to find a model configuration that, at the same time, satisfies needs of calculation efficiency and accuracy of results in an offshore environment. The properties of model configuration that have been considered in our analysis are:

- number of domains;
- horizontal grid resolution;
- number of vertical levels;
- nesting interaction;
- planetary boundary layer parameterization

The sensitivity analysis has been conducted on two relatively different synoptic situations with substantially different atmospheric stability conditions. The first is a three day unstable period spanning from the 27th October 2003 through 30th October 2003. The second is a four day stable period spanning from the 14th March 2004 through 18th March 2004. Observations at the meteorological mast FINO1 show quasistationary conditions for these two periods both concerning atmospheric stability and wind direction. Observations at FINO1 have been used not only for the derivation of atmospheric stability but also as a reference to determine the accuracy of each configuration (refer to Fig. 3). Results of the sensitivity analysis show that:

- model accuracy does not increase significantly by increasing resolution further than 10 km;
- the model is insensitive to an increase of vertical resolution;
- two way nesting does not significantly improve the accuracy of results;
- among the tested PBL schemes, the level 2.5 (Mellor-Yamada-Janijc) PBL closure present results with best agreement with observations.

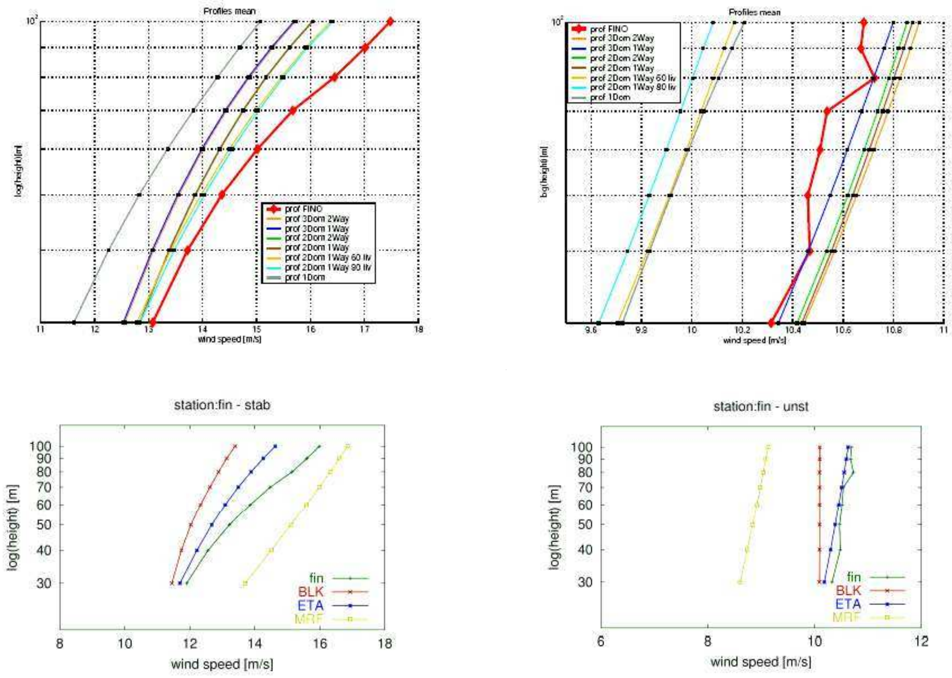

Figure 1: Results of the investigation of model sensitivity to grid configuration for the period 27-30 October 2003 (14-18 March 2004) and to planetary boundary layer configuration are shown in top-left (top-right) and bottom-left (bottom-right) pictures respectively.

4 Simulation of wind condition for the year 2004

4.1 Model configuration

In order to obtain information that may be used for a long-term assessment of the wind conditions occurring over the German Bight, the atmospheric dynamic of the year 2004 has been simulated with the MM5 model. Three nested domain have been used, with horizontal resolution of 81 km, 27 km, 9 km respectively. According to findings described in the previous sections a one way nesting interaction has been chosen between parent and child domains, the number of sigma level in the vertical direction has been limited to 24 and the ETA Mellor-Jamada-Janijc PBL scheme was used to parameterize the PBL properties. The full description of physics used for the run is reported in table 4.1. Values of zonal and meridian components of wind, relative humidity, air temperature, sea level pressure, geopotential height and surface temperature, at a resolution of 2.5 degrees derived from the NCEP/NCAR reanalysis project database, [1], provide initial and boundary conditions for the simulation. One of the issues arising when performing hind-cast simulations for a period exceeding one week is a possible “drift” of the solution away from the observed state of the atmosphere. In other words, the mesoscale model can develop features that may differ significantly from the synoptic situation described by the boundary condition. This problem can be mitigated by using nudging techniques and/or by performing many consecutive shorter runs. For these reasons the simulation has been performed as 72 single runs, each spanning a period of five days. Grid analysis nudging [2] has been applied over the solution of the mother domain.

PHYSICS	SCHEME
Planetary Boundary Layer	*Mellor-Jamada-Janjic*
Radiation	*Cloud Radiation*
Cumulus	*Grell*
Explicit cumulus	*Dudhia*
Surface scheme	*Five-Layer Soil Model*

Table 1: List of the physics option used for the simulations over the German Bight for the year 2004

4.2 Results and discussion

The comparison between model results and observed wind condition at FINO is presented in Fig. 2 and Fig. 3. The mean vertical wind profile shows a deviation from the measured one of about 1% of the measured mean wind speed in the range from 40 m up to 90 m a.s.l. The deviation at 100 m is close to 4%. It should be noted that no attempt has been done in this work to correct the effect of the meteorological mast on the measured wind speed. The anemometer at 100 m (top anemometer) is the only one free from the mast effects and therefore is taken as a reference to estimate the error of the simulation. The distribution of modeled wind direction at 100 m shows a good agreement with the observation by properly describing the main SW wind direction. Nevertheless the model appears to underestimate the frequency of wind from the SSW sector and overestimates frequencies of wind from the NWW sector. The Weibull fit of the observed and the modeled wind speed distribution reveals that MM5 is reproducing accurately the shape parameters of the distribution (k). On the other hand MM5 underestimates the scale parameter (A): the frequency of wind speeds above 25 m/s is clearly underestimated by the model.
The spatial distribution of the mean wind speed at 96 m over the German Bight is reported in Fig. 4. As expected, the distance from the cost is the most important factor driving the mean wind speed offshore. The most interesting of this analysis is that the south-nord gradient of wind speed is relatively small in front of the coast of Germany and increases if one moves from the coast of The Netherlands at about 4-5 degrees longitude east. This result, if confirmed by further measurements and from correlation with long

term datasets, can give useful indications about the ideal distance from the coast of future offshore wind power installations in the North Sea.

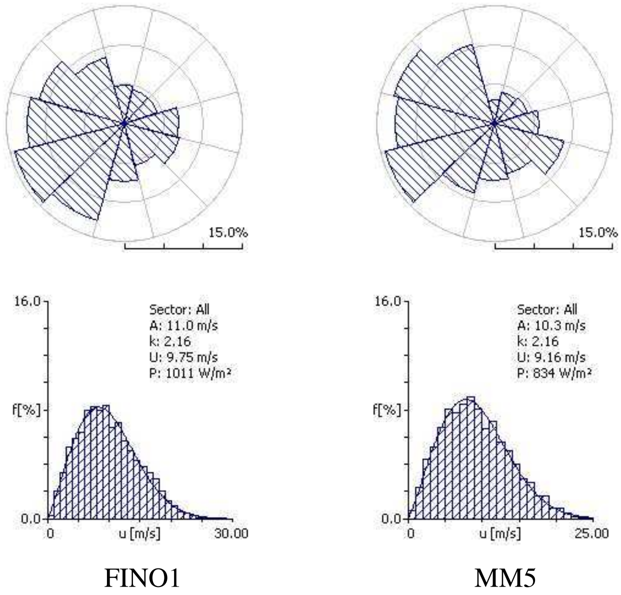

Figure 2: Wind Rose of observed wind at FINO1 at 100m (top left) and wind rose of the MM5 modeled wind speed at FINO1 (top right). Weibull fit distributions for the observed and model wind speed are reported in bottom left plot and bottom right plot respectively.

5 Acknowledgement

The authors hereby acknowledge support from the EC "Wind Energy Assessment Studies and Wind Engineering" (WINDENG) Training Network (contract n. HPRN-CT-2002-00215). Our thanks to Volker Riedel from Deutsches Windenergie Institut for the precious discussion and useful advices.

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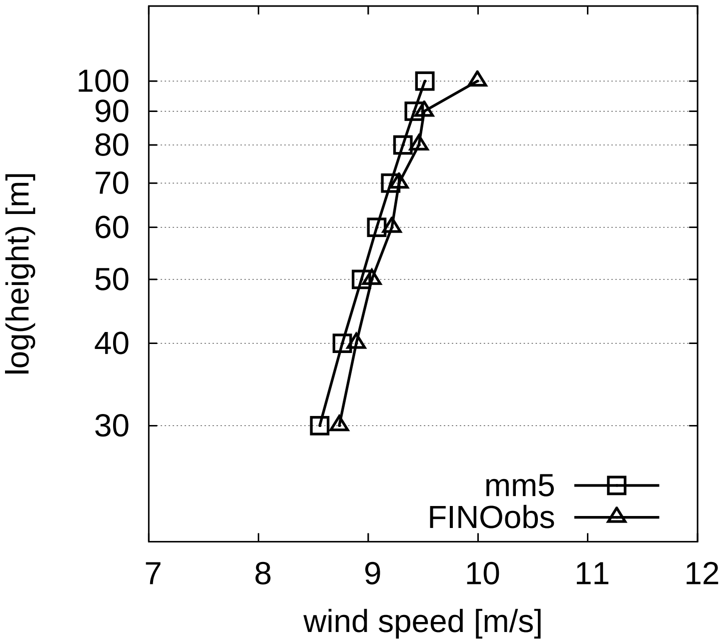

Figure 3: Mesured and modeled mean wind profile at FINO1.

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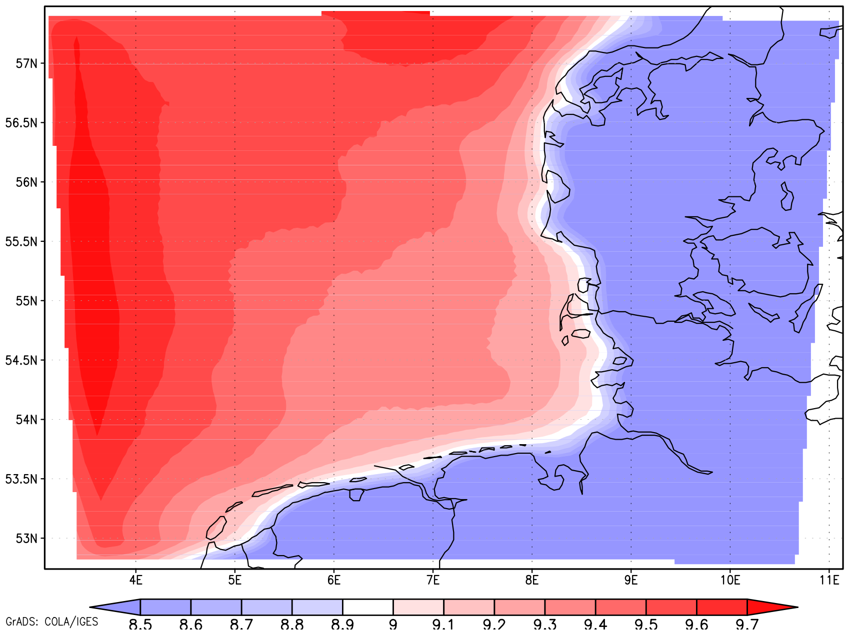

Figure 4: Mean wind speed for year 2004 at 96m a.s.l. as simulated by the MM5 model.